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Environmental challenges induced by extensive use of face masks during COVID-19: A review and potential solutions

Kajanan Selvaranjan^a, Satheeskumar Navaratnam^{b,*}, Pathmanathan Rajeev^c,
Nishanthan Ravintherakumaran^d

^a Department of Civil Engineering, University of Moratuwa, Sri Lanka

^b School of Engineering, RMIT University, Australia

^c Department of Civil and Construction Engineering, Swinburne University of Technology, Australia

^d Faculty of Engineering, University of Jaffna, Sri Lanka

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ABSTRACT

The ongoing COVID-19 disease significantly affects not only human health, it also affects the wealth of country's economy and everyday routine of human life. To control the spread of the virus, face mask is used as primary personal protective equipment (PPE). Thus, the production and usage of face masks significantly increase as the COVID-19 pandemic still escalating. Further, most of these masks contain plastics or other derivatives of plastics. Therefore, this extensive usage of face masks generates million tons of plastic wastes to the environments in a short span of time. This study aims to investigate the environmental impact induced by face mask wastes and sustainable solution to reduce this waste. An online survey was carried out to identify the types of face mask and number of masks used per week by an individual from 1033 people. Based on this survey and available literature, this study quantifies the amount of plastics waste generated by face masks. However, this survey was limited with certain ages, country and durations (July–August 2020). Thus, the prediction of plastic waste generation, only provide fundamental knowledge about the mask wastes. Results revealed that there is a huge plastic waste remained in land and marine environment in the form of mask waste, which will contribute to micro-plastic pollution. Therefore, this paper also highlights the sustainable approach to the mask production by integrating the use of natural plant fiber in the woven face mask technology to reduce the plastic waste induced by masks. Further, upcycling the mask waste and producing construction materials also discussed.

1. Introduction

The ongoing COVID-19 pandemic significantly induced uncertain environments for every human, business, education, job, and economy of each country. There is no viable meditation to prevent the spread of this deadly coronavirus disease (Fadare and Okoffo, 2020). The use of personal protective equipment (PPE), social distance, travel restrictions and lockdown were currently employed to reduce this spreading level of coronavirus (Rubio-Romero et al., 2020; Sun et al., 2020). This ongoing pandemic situation created that wearing mask is must for every human life. There are various types of masks such as surgical, N95, and commercial fabric/cloth masks used to tackle the ongoing pandemic situation (Fig. 1).

According to the World Health Organization (WHO) study, in USA about 89 million medical masks are anticipated to be required to respond the COVID-19 as this crisis is likely to persist for some time (Xiang et al., 2020). Further, the plastic innovation hub has identified

that the domestic demand for the mask in UK is around 24.37 billion per year (Liebsch, 2020). As of February 2020, China has raised its daily production of medical masks to 14.8 million. The Japanese ministry of finance, trade, and industry recorded that more than 600 million face masks required per month of April 2020 (Fadare and Okoffo, 2020). The increasing use of mask significantly increases the production of mask and it consumes higher amount of energy. A study by Klemes et al., 2020a,b shows that a mask production consumes about 10–30 Wh energy and releases 59 g CO₂-eq greenhouse gas to the environment. Further, ever increasing uses of face mask also increase the landfill and medical waste. Most of these face mask wastes contains either polypropylene and/or polyethylene, polyurethane, polystyrene, polycarbonate, polyacrylonitrile, which add plastic or microplastic pollution to the environment (Akber et al., 2020). This indicates that current ongoing pandemic, increases the environmental pollution and negative impact to human and animal health. Therefore, sustainable solutions need to reduce the environmental impacts, while meeting the mask demand.

* Corresponding author.

E-mail address: sathees.nava@rmit.edu.au (S. Navaratnam).

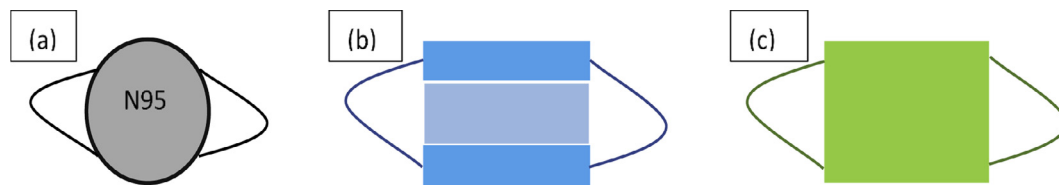


Fig. 1. Example of different type of masks: (a) N95 mask; (b) surgical mask; and (c) cloth mask.

Governments and publics have already begun to explore the alternative solutions including the reuse, reprocessing and disinfection of approved disposable masks, and producing biodegradable masks and homemade or non-certified masks (Rubio-Romero et al., 2020). The effectiveness and impact of these alternatives are not yet understood and practiced by every people. Thus, this study conducts the online survey to identify the mask types, duration and disposal method being employed currently. Furthermore, a comprehensive review was conducted to find the material contents in the mask, impact on the mask wastes and suggest a sustainable upcycling solutions to the mask waste.

2. Data collections

Online survey and literature review were employed to achieve the objectives of this research. Following sub-sections describe the survey and review methods.

2.1. Online survey

The data is collected confidentially by conducting an online survey among different age groups (i.e. children (12–15), teenagers (16–25) and adults (26–65)) in many countries, particularly Australia, America, UK, Singapore, Sri Lanka and India. This survey was performed on a total of 1033 individuals for a period of one month (5th July 2020 – 6th August 2020) at COVID-19 pandemic outbreak. In this survey, the questions were focusing following parameters: the types of mask (i.e. surgical mask, N95 mask, cloth mask or both); the amount of masks usage per week; and methods of mask disposal (i.e. wash and dispose, flush in toilets, put in appropriate bin, burning and throw away). The aim of survey is identifying the mask waste generation and provide the fundamental information about effect of the mask waste to the environment. Due to this, the survey did not focus mask waste generation by gender basis (male/female). This limitation could be creating the variation in the amount of mask waste generation. However, finding of this study provide the fundamental knowledge of mask waste generation, which will help to develop the waste control and management policies.

2.2. Literature review

The data collection approach of the current study was focused on the review of journal articles related to rapidly growing COVID-19. The data and knowledge on this particular topic are outstanding, showing the severity of the pandemic crisis. Such information is collected not only from scientific literature, but also from numerous reliable online resources, journals, and policy and media reports. The literature was gathered from 2nd February 2020 (at the peak of the first wave of COVID-19 pandemic) until the completion of this review (30th November 2020). The data collection concentrated on a following categories of: (a) precautionary measures used to monitor the forms of COVID-19; (b) the components of the mask; (c) problems relating to the disposal of the mask; (d) and sustainable solutions to address the effect of waste mask.

Two reliable and detailed databases such as Scopus (scopus.com) and Web of Science (webofscience.com) were used to search for the relevant topics. As they provide high coverage of similar papers to the subject of this review and minimize the risk of missing any relevant

document. To start with the searching process, a keyword of “COVID-19 or COVID 19” from 2014–2020 was used to develop the final search criteria. The initial results of this search through Scopus and Web of Science (WoS) databases were 26920 and 48406, respectively. Additional limits were given for filtering the quantity of the publications to exclude the irrelevant sources. In that way, the findings decreased to 415 for Scopus and 19 for WoS using key terms such as “COVID-19” AND “Masks” AND “Wastes”. In addition, the results were restricted to 131 and 7 journal articles in Scopus and WoS, respectively by using the keywords “COVID-19” AND “Masks” AND “wastes” AND “Environmental” as shown in Fig. 2.

3. Survey results and discussion

Survey results and current issue from the mask waste are presented in the following sections.

3.1. Survey results

The data obtained from the online survey was confidentially analyzed in age-wise. Fig. 3 shows the percentage of people who participated in the online survey with different age group. For this survey people with age of 26–45 show more interested to participate.

Fig. 4 shows that about 80% of people always wear masks and about 16% people occasionally wear the mask. This indicates that about 96% of individuals understand the importance of wearing the mask during the pandemic. However, 3% of them rarely used the mask, which may be due to lack of awareness and given less importance of the situation. About 1% of people have never used the mask due to their pre-existing medical condition.

The type of masks used by people who participate in the survey was shown in Fig. 5. This figure indicates that highest population (i.e. 40%) of people are used surgical mask for their personal safety. Whilst, the cloth mask is the second highest for use (34%) as it's cheaper than N95 mask and also be self-made. The N95 mask is highly recommended by WHO, only about 9% people use it as it is expensive than other mask types.

Fig. 6 shows the quantity of waste mask generated by a person per week. This quantification may varies depending on the duration of mask usage, type of mask, degree of people's hygiene, place visited, etc. However, the results from this survey illustrate the fundamental quantification value of mask waste. The survey reveals that more than 25% of people generate 5 masks waste per week. Consequently, at least one mask waste was created by an individual per day.

Mask wastes generated from each country (i.e. Sri Lanka, India, Australia, Singapore, UK and USA) was derived and shown in Fig. 7. This was calculated based on the minimum (i.e. 1) and maximum (i.e. 5) number of masks used by individual (Fig. 6) with the population of people at age between 16 and 65, which were obtained from census data (Clark, 2020; Erin, 2020; Hirschmann, 2020; Plecher, 2020a,b,c). Fig. 7 shows the fundamental idea of mask waste generation per week from Sri Lanka, India, Australia, Singapore, UK and USA. During this peak of the first wave of COVID-19 crisis most of these countries are went under lock down. Hence, the transportation in public and private vehicles, walking was very less, which may have affected the lower percentage of mask usage per week. Therefore, if the usage of mask is con-

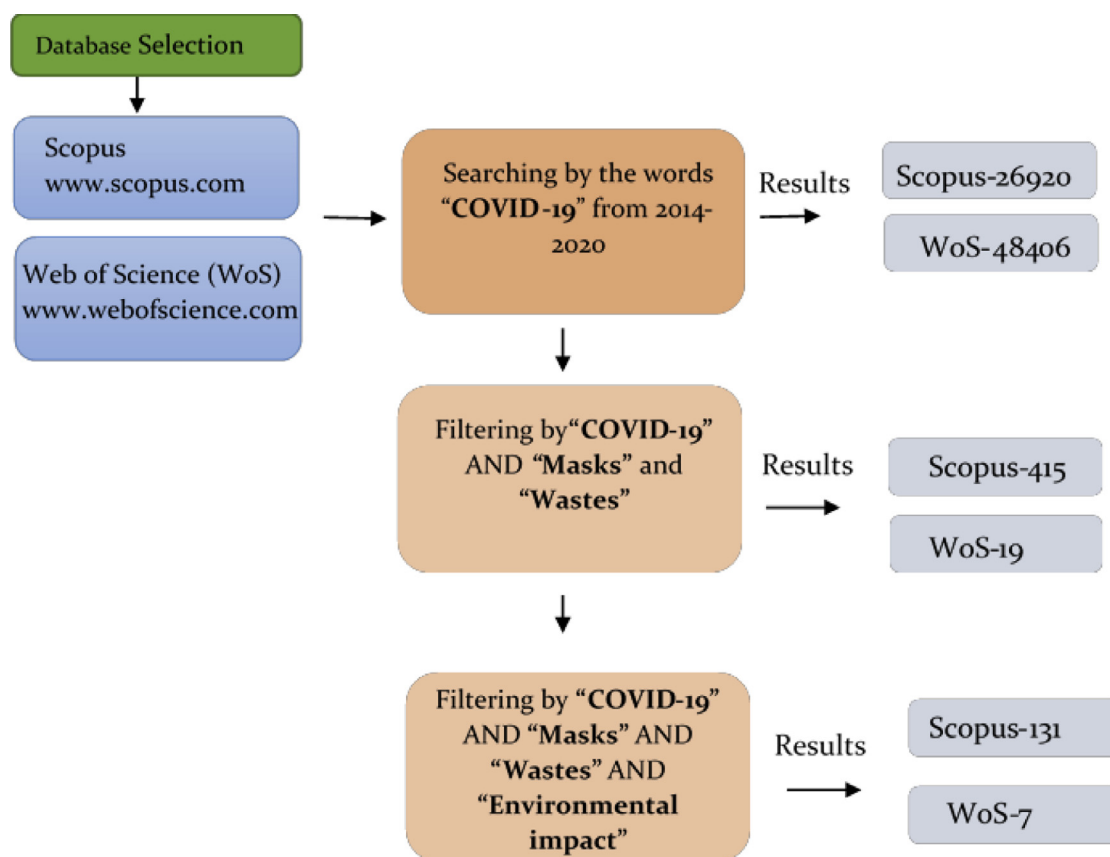


Fig. 2. Summary of total number of reviews.

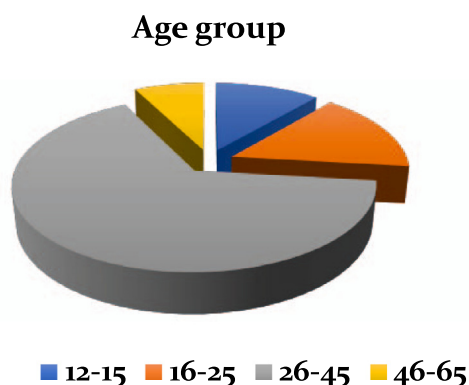


Fig. 3. Different age group people who participated in the online survey.

sidered worldwide with the whole population, it is expected to reach the peak level, which will eventually create a significant amount of plastic waste to the environment.

A study by Akber et al. (2020) highlighted that the amount of polypropylene in surgical mask and N95 mask are 4.5 g and 9 g, respectively. Total maximum and minimum amount of polypropylene generated per week from different countries were calculated based on the mask wastes generation per week (Fig. 7). Fig. 8 shows that minimum about 2.5 kt, 0.6 kt, 0.04 kt plastic (i.e. polypropylene) waste were generated, respectively from India, USA, Australia per week. This indicates that this Covid-19 pandemic will impact not only the health and economy, but it will also impact the sustainability of environment.

In order to identify the mask disposal method, the survey question was generated with six general disposal methods: 1) disposed into the mixed waste bin; 2) disposed into the hazardous waste bin; 3) burning; 4) flush in toilets; 5) wash and disposed into mixed waste bin; and 6)

throw away. Fig. 9 shows that about 34% and 11% individuals dispose the mask as the mixed waste and hazardous waste, respectively. This indicates that about 45% of them appear to be extremely responsible for the solid waste that they produce. Whereas 19% individuals recklessly throw away the face masks in the street and 12% of people are wash and dispose the mask. This has the potential to create the environmental issues due to its indecomposable nature. Consequently, has high possibilities in creating a future global warming issue. About 3% of people flush the mask in toilets while 10% people burn the mask. This 10% of individuals are responsible for the contamination of the air by the releasing adverse compounds into the atmosphere. Ultimately, this phenomenon could create chronic respiratory illness (Stafford and Jones, 2019).

Further, if the prevailing pandemic situation is to be continued, the people should adapt to live with the safety precaution, which can give them a healthy life. Thus, the mask production will be significant and increase the mask waste in near future. The mask is made of different types of plastic, which is not decomposable, and it induce the negative impact on the environments. Therefore, without disrupting the economy, any innovative steps can be taken with respect to the environment and the social well-being of people. On the other hand, instead of using different types of plastic raw material, steps should be taken to replace some decomposable raw material in production of face masks. In addition, the waste mask can be recycled by different methodologies and used as a supplementary material in any innovative products such as construction materials.

3.2. Material contents in the masks

The survey results highlighted that higher population of people are using surgical mask to protect their self from the COVID-19 virus. This surgical face masks (Fig. 10a) are made of non-woven fabric that has

Fig. 4. Importance of mask usage.

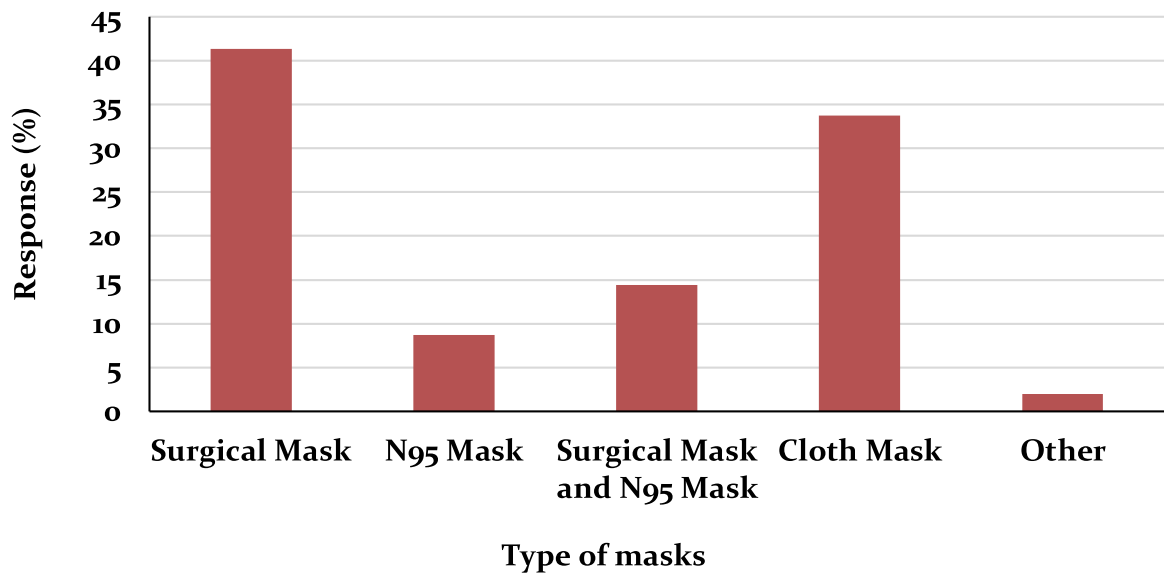
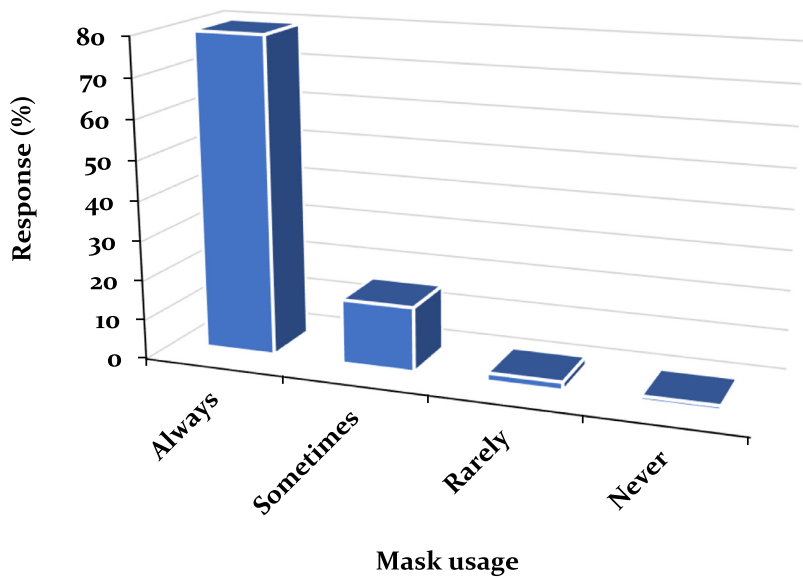


Fig. 5. Types of masks used by people.

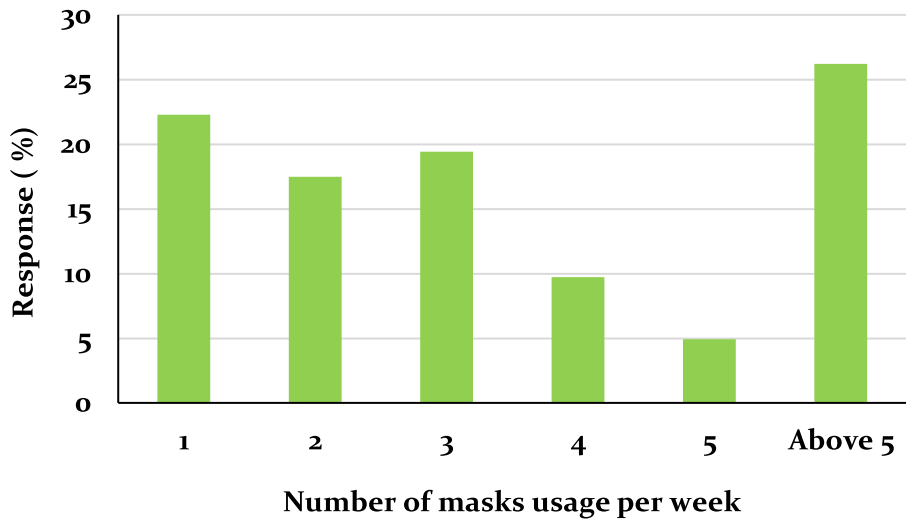


Fig. 6. Number of masks usage.

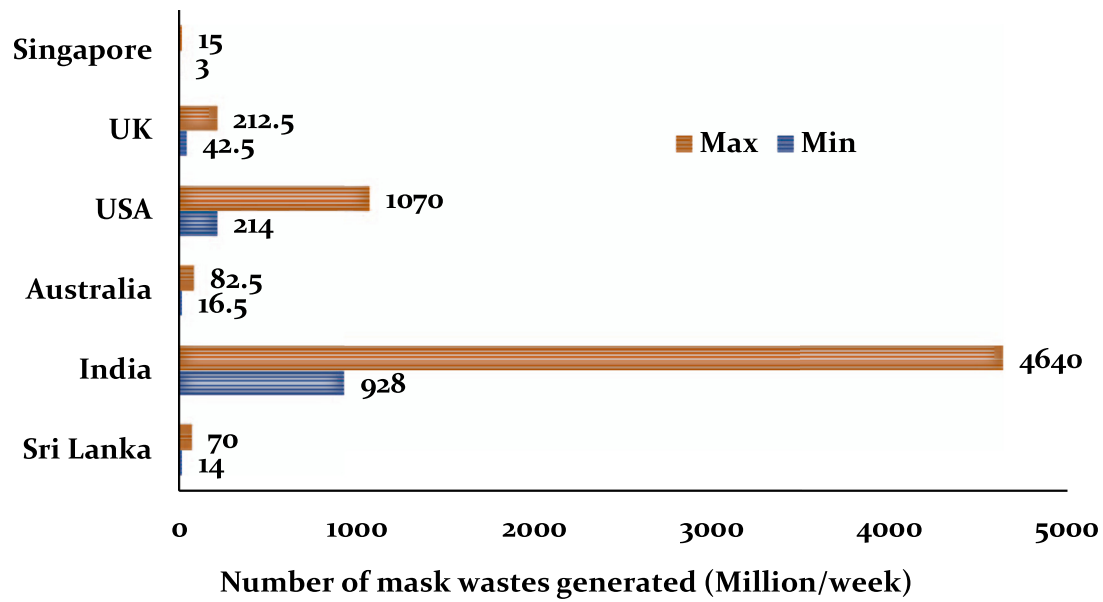


Fig. 7. Total amount of mask waste generated per week.

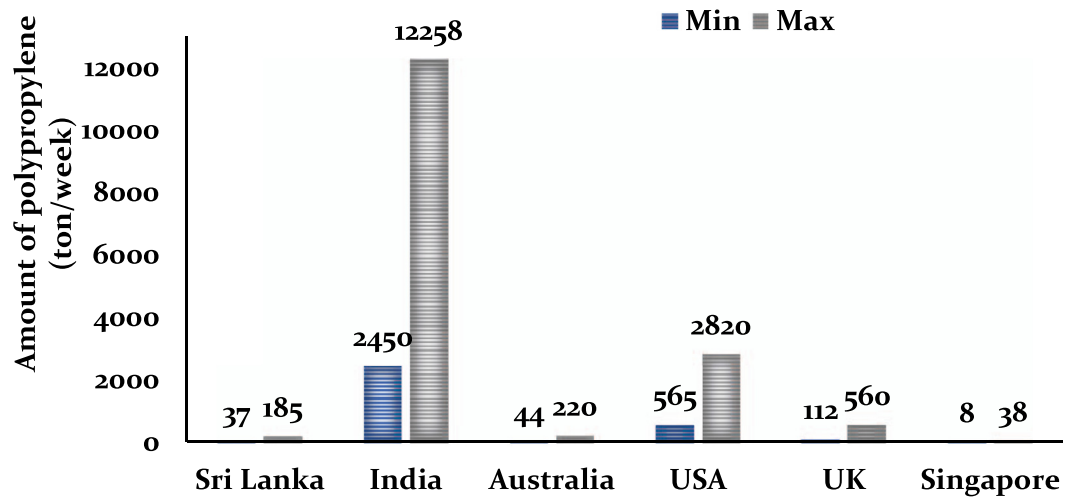


Fig. 8. Total amount of estimated polypropylene from face mask wastes per week.

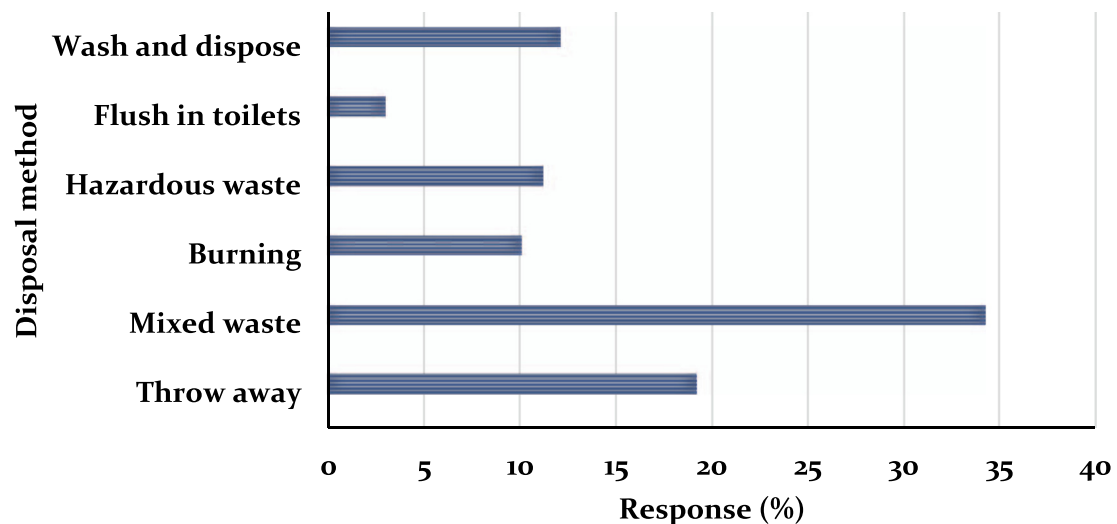


Fig. 9. Disposal method of mask waste.

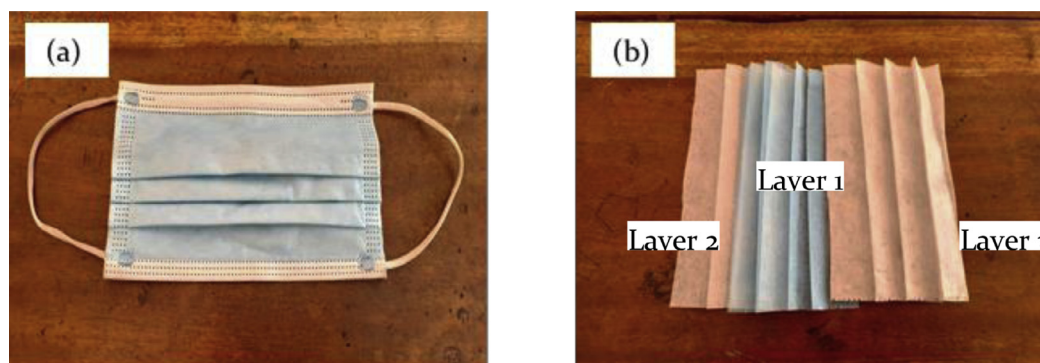


Fig. 10. Structure of surgical mask: (a) surgical mask (b) three layers in the surgical mask.

better filtration of bacteria and air permeability, while remaining less slippery than woven fabric. Based on the barrier properties and breathing resistance, the ASTM F2100 (ASTM, 2007) and EN ISO 15223-1 (BS EN ISO 15223-1, 2016) classified this mask into different types (i.e. low barrier, moderate barrier and high barrier) (Chellamani et al., 2020). This surgical mask mainly consists of three layers (Fig. 10b) such as outer hydrophobic non-woven layer (translucent), middle melt-blown layer (generally in white colour), and an inner soft absorbent non-woven layer (green, blue, or white colour). The polypropylene (i.e. known as plastic) is used as a major material to produce this surgical mask. However, other polymers like polystyrene, polycarbonate, polyethylene or polyester are also used to produce this mask (Akber et al., 2020).

The highly recommended mask to prevent the virous spreading is N95, which consists of four layers of material: an outer layer of spun-bond polypropylene; a second layer of cellulose/polyester; a third layer of melt-blown polypropylene filter material; and an inner (fourth) layer of spun-bound polypropylene. The typical raw materials used to produce N95 mask is polypropylene similar as the surgical mask (Barycka et al., 2020). Further, the weight of the surgical and N95 face masks is 3.5 g and 18.14 g, respectively. The ear loops of both face masks were made of natural and synthetic polyisoprene (i.e. latex-free) rubber. While, the ear loops in the cloth mask was made by cloth. There are mostly two kinds of cloth masks, "commercial cloth masks" and "homemade cloth masks" (Santarsiero et al., 2020a; Santarsiero et al., 2020b). These cloth masks are made of multi layered of cloth like old t-shirts and sewing material (Ayse et al., 2020). Cloth mask are also made of cotton and nylon, which have water resistant property. Furthermore, the fabric of cloth mask comes under the non-medical mask category, whilst the surgical and N95 masks are known as the medical mask. The filtration performance of these cloth masks are depends on many variables, such as thread count, number of layers, fabric type, and resistance to water (Chughtai et al., 2020). The filtration efficiency of cloth mask is varying as some fabrics filter better than others. However, the filtration efficiency of cloth mask is lower than that of from medical mask.

4. Impact of mask waste on environment

The mask wastes are increased across the world as the people are not following the appropriate disposal methods for the used mask. Thus, it creates a new environmental challenge. Further, there are no appropriate mask or plastic waste collecting method specified in whole countries or part of the region in Sri Lanka, India, Pakistan and China (Sangkham, 2020). This is adding a vast amount of plastic and plastic particle waste in the environment, which may end up in the streets and landfills. Besides, it gets into the waterways and reach the fresh water and marine water. This adds the presence of the plastics into the aquatic medium. The health and environmental effects of plastic and plastic particles due to the inappropriate disposal of facemasks were also highlighted by number of literatures (de Sousa, 2020; Parashar and

Hait, 2021; Sangkham, 2020). Furthermore, the production of the face masks also contributes the emission of CO₂, which will potentially contribute to the global warming (Liebsch, 2020). The processes of propylene, small aluminum strips and polypropylene in the production of N95 and surgical mask contributes the significant amount of CO₂ emission to the environments. Furthermore, production of fabric, sewing and weaving process of cloth mask fabrication also contributes the CO₂ emission to the environments (Liebsch, 2020).

The N95 mask production release 50 g CO₂-eq per single mask, excluding the transportation process (Klemeš et al., 2020a). Surgical mask is embodied with 59 g CO₂-eq per single and the highest share is from the transportation process (Klemeš et al., 2020a). Whilst, the cloth mask production contributes about 60 g CO₂-eq greenhouse gas emission per single mask (Klemeš et al., 2020a). However, this would create a massive impact to the atmosphere because, millions of face masks are produced all over the world to control the pandemic situation. The face masks used by medical examiners in hospitals are carefully collected as its hazardous waste. A study was conducted in the UK and analyzed that if each individual uses one disposable surgical mask every day for a year, this would create over 124,000 tons of unrecyclable plastic waste 66,000 tons of contaminated waste and 57,000 tons of plastic packaging (Ayse et al., 2020). However, there is currently no specific waste stream for these products if it used by the public. Mostly, it is thrown recklessly in the streets or collected as a mixed waste.

In the handling of urban solid waste and hazardous medical waste, the pandemic has led to a significant challenge. The collected hospital face masks and other mixed waste are sent to the incineration and landfill. However, due to the existence of the plastics in the mask, such methodologies often have the potential to cause adverse environmental effects. Most plastics are chemically stable, resistant to corrosion and, difficult to degrade by microorganisms (Webb et al., 2013). Yet they prefer to remain in the soil and pose environmental threats. The solution that allows the chemical energy content of plastics to be recovered for useful purposes is the incineration of medical waste coupled with waste heat recovery. For medical waste incineration, the WHO has suggested 900 °C and 1200 °C to guarantee safe destruction, but most of them are unaware of the temperature range (Klemeš et al., 2020a). However, with heat recovery, there are limitations to the widespread use of incineration. Public worries about dioxin and furan trace emissions can become troublesome. The transportation of those waste to relevant disposal site also consume energy and release greenhouse gases to the environment. Recent study by Kumar et al. (2020) stated that 10 ton of PPE waste including face masks travelled 10 km for the relevant disposal site resulted in total global warming potential (GWP) impact of 2.76 kg CO₂-eq.

The mask littered in the soil can impact the fauna in which it causes entanglement and can cause death (Fig. 11). For instance, it is reported in Columbia that a bird was tangled in a discarded coronavirus facemask in a tree. Then died after the mask is wrapped around its body and beak (Boyle, 2020). Further, when the mask is mistaken for food by an



Fig. 11. Threat to birds due to usage of mask (Boyle, 2020).

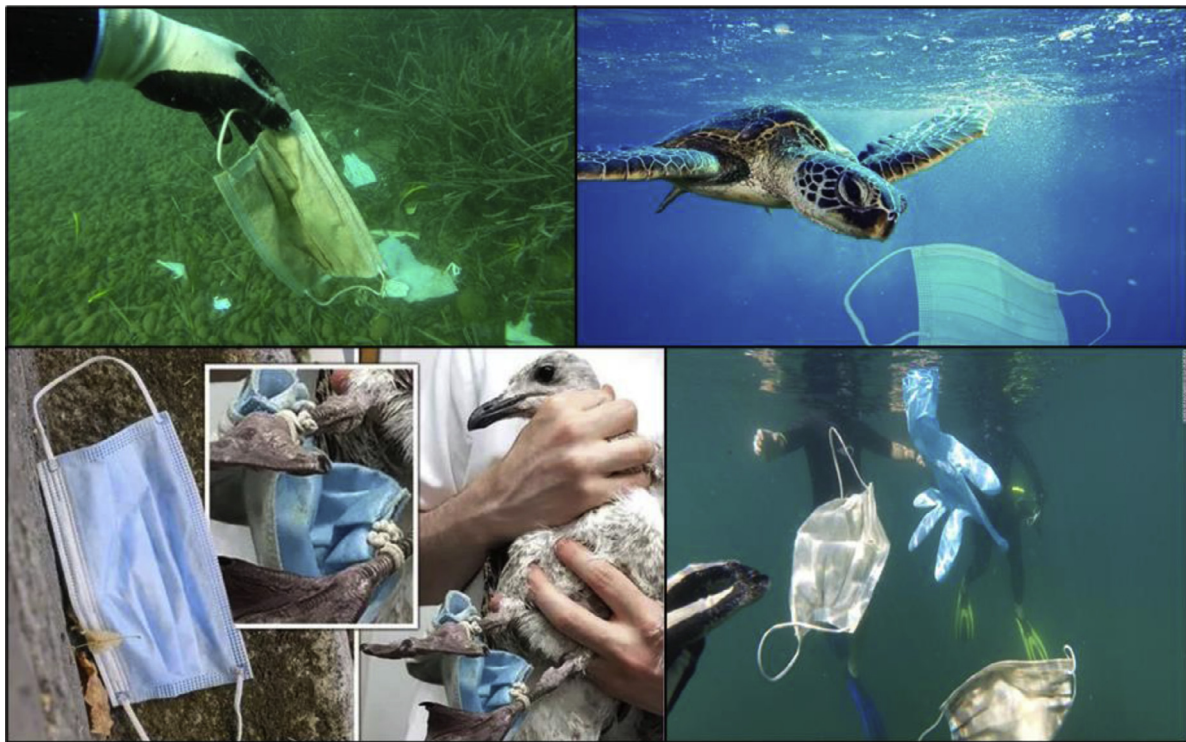


Fig. 12. Threats to aqua life due to usage of face masks (Ashworth, 2020; Edmond, 2020; Harris, 2020; Kassam, 2020).

animal, which is unfortunately a common occurrence, the plastic can fill stomachs, decrease food intake, cause animals to starve and die.

The mask wastes also conveyed into the rivers and enters the fresh water and sea water. This creates the plastic pollutions to the aquatic medium (Fig. 12). Marine plastic adsorbs toxins and organic contaminants, which ensures the pollutant particles bind as a toxic film to the surface of the plastic (Williams-Wynn and Naidoo, 2020). As a result, it is also possible to poison the marine animals, which ingest plastic. It may destroy them directly, or weaken them, rendering them more vulnerable to other threats (Ferraro and Failler, 2020). Ingested plastic can interfere with impair reproduction, growth and development of young (Klemeš et al., 2020b; Yang et al., 2020). Further, it can also cause entanglement, which lead to death in aquatic fauna like birds and other under water animals. Fragmentation of the macro plastic in the mask could occur due to various abiotic factors such as photodegradation, weathering, corrosion, and aquatic immersion forming the secondary micro plastics (Yang et al., 2020). Hence, bio accumulation of such microplastic occurs in the major food web to human existence and cause

accumulation of toxins. This causes not only detrimental environmental effects, but also economic and social effects as shown in Table 1.

5. Solutions to reduce the mask waste

Plastic is a significant continuing debate, which is not biodegradable material and induces further climate change pollution by affecting land and groundwater (Thompson et al., 2009). To overcome this issue, different management and assessment approaches have been used such as incineration and landfilling (Vanapalli et al., 2021). However, these are no longer preferred options to create the circular economy. Reduction of the plastic usage is completely not possible as it is an inevitable part of human behaviour, hence the search for another option to manage plastic waste is necessary. Therefore, governments are employing numerous international agreements to regulate plastic pollution. They include the Basel convention and its 2019 amendment, the United nations convention on the law of the sea, the international convention on the prevention of ship pollution, and the United nations global marine litter partnership (Patrício Silva et al., 2020).

Table 1

Environmental, economic and social impact of ocean plastic pollution in terms of sustainability.

Category	Issue	Consequences	Ref.
Environmental	<ul style="list-style-type: none"> • Microplastic enter food chains via ingestion. • Entanglement of the plastic waste. • Contain toxic chemicals as an additive. • Adsorb persistent organic pollutants (POP)s and heavy metals. • Occurrence of the plastic in the aquatic environment. • Improper disposal of facemask reaching water bodies. • Microplastics create a new microbial niche. 	<ul style="list-style-type: none"> • Enter the major food web to human existence. • Bio accumulation of toxins. • Cause the suffering and death of charismatic marine animals (e.g. seabirds, turtles, and crustaceans). • Toxic chemicals of plastic can be released during the degradation processes (either chemically or biologically) in the open environment. • Bioaccumulation of the POP and heavy metal in aquatic organisms, eventually enter the food web. • Environmental deterioration and degradation up to climate change. Contribute to drought and global warming due to carbon emission. • Act as a medium for further outbreaking of COVID-19 since the particles tends to proliferate microbes and disseminate in the food chain and/or direct attacks. • Affect microbial habitual and the environmental processes in aquatic ecosystems. 	(Haque et al., 2021; Klemeš et al., 2020b)
Social	<ul style="list-style-type: none"> • Pollution of aquatic environment or shore with plastics or plastic particles. • Ingesting and entanglement of the plastic. 	<ul style="list-style-type: none"> • Reduces aesthetic and recreational value thus, impacts to human social and mental stability. • Images of plastic covered shorelines or charismatic megafauna entangled, or ingesting plastics are visually impactful. 	(Stafford and Jones, 2019; Yang et al., 2020)
Economical	<ul style="list-style-type: none"> • Environmental and social impacts of plastic and plastic particles. 	<ul style="list-style-type: none"> • The clean-up activities, lifesaving activities of the aquatic bodies are expensive. • Tourism industry experiences significant loss. 	(Zhang et al., 2020)

Reusing and recycling are viable options for plastic waste management, but prior to that identification of the condition of the plastic is required and cleaning or repairing steps are necessary according to its source (Liang et al., 2021). The collected plastic wastes are shredded initially and sorted using the techniques like spectroscopy, X-ray fluorescence, flotation, magnetic or density separation. Then the optical sorter is used to differentiate the colour, and the separated plastics are melted and extruded into pellets for reuse. The recycled plastics are sold to local plastic manufacturing firms that can ultimately manufacture useful products such as engine oil, textile, footwears, and concrete additives. These process is financially not feasible as it is expensive, hence as an alternative way, the automated separation of various plastics could be adopted prior to the shredding (Williams-Wynn and Naidoo, 2020).

Furthermore, medical waste also contribute significantly to the global plastic waste (Huang and Huang, 2007). These wastes should be given a special consideration for disposal as it might be hazardous or radioactive. As a first step, the classification of hospital waste at its origin is done for the management of waste, which has the possibilities to avoid the spread of infection to the waste handlers. The waste is collected in separate bins or bags with a clear identification and then the waste containing bags must be disinfected and sealed with double-layered plastic bags (yellow color) prior to transportation from the origin. According to WHO, the biomedical waste includes 10% of infectious hazardous waste, and 5% of toxic or chemical waste (Ilyas et al., 2020). The commonly used disinfection techniques for the management of hospital wastes are pyrolysis technique and microwave technique. The temperature is sustained at around 540°C–830°C in high-temperature pyrolysis, which involves pyrolysis-oxidation, plasma pyrolysis, induction-based pyrolysis, and laser-based pyrolysis (Ilyas et al., 2020). This effectively offers advantages such as low emission rate, reduction of inert residual volume by up to 95% and reduction of mass by up to 90% (Ilyas et al., 2020). Another technique used for the medical waste is the medium microwave technique, which works within the temperature range of 177–540 °C. The key benefits of the microwave technique are comparatively lower energy and action temperature, limited heat loss, and less environmental burden without harmful residue during the disinfection phase (Haque et al., 2021).

There is a dramatic rise in the generation of plastic waste during the COVID-19 due to the increased use of face masks and change in customer

preference to single use mask due to the hygienic problem (Patrício Silva et al., 2020). Therefore, many advanced waste management methods with minor variations in the general treatment of medical waste have been developed (Sangkham, 2020). Shortly after the first outbreak of COVID-19 in South Korea, 'Special Safe Waste Management Measures against COVID-19 was enforced on 28 January 2020 (Sangkham, 2020). COVID-19 waste cannot be kept for more than 24 h as per its guidelines and must be incinerated on the same day of collection. Therefore, most of the COVID-19 waste is sent for incineration at a temperature above 1100 °C (Sangkham, 2020). The microwave technique is often used in conjunction with autoclaving in the case of COVID-19 waste disinfection, where steam is used for sterilization (in the temperature range of 93–177 °C). The chemical disinfection technique is commonly used in combination with prior mechanical shredding for the pre-treatment of COVID-19 waste.

The polypropylene (i.e. plastic) used to produce the mask is according to the technical standards (Huang and Huang, 2007). Currently, this mask is discarded after the usage, as they are sensitive to heat and cannot tolerate high heat. However, due to the huge demand of the face masks caused by the COVID-19 crisis, the lifespan of the usage of face masks is investigated for the reuse (Chua et al., 2020). Reuse can be done using a strategy called mask rotation. In this strategy, rotation of the mask used each day can be carried out, allowing them to dry for long enough periods so that the virus is no longer viable (> 72 h) (SAGES Webmaster, 2020). Proper storage for this technique requires either hanging the face masks to dry, or keeping them in a clean, breathable container like a paper bag between uses (Vanapalli et al., 2021; Williams-Wynn and Naidoo, 2020). Re-processing/decontamination is carried out by various methods like moist heat, dry heat, UV treatment, hydrogen peroxide (H₂O₂) vaporization. The H₂O₂, dry heat techniques have the opportunity for reprocessing of personal protectives (N95 face masks) and their re-use (Ilyas et al., 2020).

The recycling the mask by the appropriate processes is one of the alternatives used to reduce the plastic pollution generated by mask waste. Broadly, there are two ways for recycling such as primary recycling and secondary/chemical recycling. Primary recycling is the reusing of the product in their original structure. In the secondary recycling, the mask consisting of thermoplastic can be reused (Lackner, 2015). As they can be re-melted and re-processed into various end products; either to

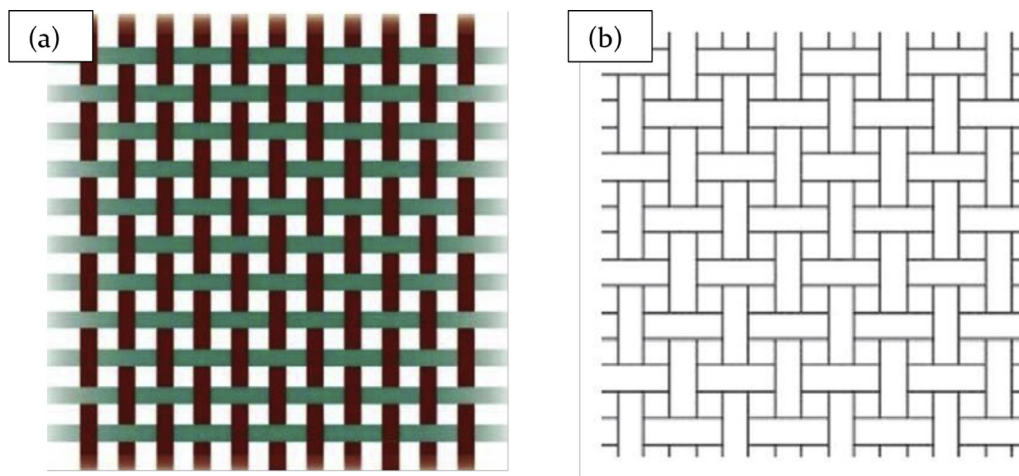


Fig. 13. Woven technology in: (a) surgical mask (Chellamani et al., 2020); and (b) plant fibre (Misnon et al., 2014).

produce the same product or composite products. Hence, this method can be employed to recycle the mask in a useful manner. However, considering the cost of a brand-new mask, this recycled mask is expensive for processing, also the filtering efficiency and the quality of the recycled mask is less than that of a new mask (Chua et al., 2020). Therefore, it is important to further examine for other alternatives to reduce the mask wastes.

Biodegradable mask is one of the modern sustainable alternative options to reduce the mask that induces plastic waste. The polypropylene in the mask can be replaced with other substitute organic and biodegradable materials with similar mechanical, physical and chemical properties such as light weight, high tensile strength, ecological safety, low cost and high biodegradable potential (Glukhikh et al., 2020; Samper et al., 2018; Siracusa and Blanco, 2020). The bioplastic and biodegradable polymers can be an option to replace the polypropylene. Bioplastic is a type of biodegradable plastic derived from biological substances rather than conventional plastic made of petroleum. The production of the mask using bioplastics must follow the standard requirements such as elasticity, water resistance and filtering properties. In general, due to the existence of polypropylene, all these properties can be found in bioplastics (Duc et al., 2011). This biodegradable plastic reduces the CO₂ emissions by 30%-70% compared with the conventional one (Lackner, 2015). The biodegradable polymers can be obtained from different families like biomass production from agro resources such as polysaccharides (starches, lignocellulose), proteins, lipids and micro-organisms. Natural fibers such as cactus, banana, avocado, lotus, sisal, straw, hemp, maize bamboo, hemp, coffee and sugar cane have capability to meet the standard requirements to produce the mask (Luhar et al., 2020; Ramesh et al., 2017; Yan et al., 2016).

Furthermore, Fig. 13a shows the woven technology used in the filter of the surgical mask. Similar filters can be made with biodegradable plant fibers (Fig. 13b). Polysaccharides such as bamboo, hemp, coffee and sugar fibers are used to develop a bio mask and it prevents pollution caused by mask disposal and they can be processed and recycled (Ho, 2020; Layt, 2020; Staff, 2020). Tea leaf waste also can be used to produce the filter part of the mask as it contains polypropylene and enhances the properties of poly lactic acid (PLA) in bioplastics (Ferraro and Failler, 2020). This indicates there is a possibility to use natural fibers waste and raw natural fibers to produce a cost-effective sustainable biodegradable green mask. Sugar cane waste mask (Layt, 2020), Coffee-Based Face Masks (Ho, 2020) and Hemp Fiber mask (Staff, 2020) are currently available biodegradable masks. These types of biodegradable masks are manufactured with 99.99% dual antibacterial technology and have the high filtration capacity. Currently many research studies are going on developing the required specification for biodegradable

mask to bring it to the standard of medical mask (Choi et al., 2021; Santarsiero et al., 2020a; Santarsiero et al., 2020b).

Although biodegradable face masks are made, individuals who are unaware of these benefits may not appear to alter their behavioral patterns from single-use plastics. Such masks are unpopular because they are only made in limited countries. Whilst the biodegradable face mask made from bioplastics claims to be degradable, there is still an uncertainty about the complete degradable nature of the biodegradable mask whereas a number of limitations still restrict it. For example, some plastics such as PLA require industrial scale composter to biodegrade (Vanapalli et al., 2021). Consequently, it is also mandatory and costly to build the appropriate infrastructure for biowaste management. Therefore, more investigations and research studies are needed, to assess the effectiveness and lifespan of sustainable biodegradable mask.

The use of recycled waste face masks as a composite material in various applications from all other alternatives to solve the global plastic crisis (i.e. mask pollution) would be a better approach in terms of circular economy. This is not only promotes the removal of collected waste from landfill sites, but also helps to reduce the production of waste in the first place. Substantially, it is restricting the use of natural resources and limiting the effects on the environment. A novel approach to reduce the plastic waste is convert this into construction materials. Different types of recycling methods such as mechanical recycling, chemical recycling and incineration have been used for the extraction of polypropylene from plastic wastes. In mechanical recycling, the polypropylene is separated from other forms of resin, washed to remove dirt and contaminants. Then grinded and compressed to minimize the particle size of the plastics, accompanied by heat extrusion and reprocessing into new plastic products. Chemical recycling allows plastic waste to be turned into initial monomers or another useful chemical (Ahmad et al., 2015; Canopoli et al., 2020; Matei et al., 2017; Poulakis and Papaspyrides, 1997; Rahimi and García, 2017).

The extraction of the pure polypropylene from the plastic waste containing various types of polymers could be achieved by pyrolysis method because it does not require pure plastics. The polypropylene pyrolysis was carried out using a two-stage continuous process equipped with auger and fluidized bed reactors linked in sequence (Park et al., 2020; Park et al., 2019). There have been different forms of reactors, such as stirred, screw kiln, circulating sphere, fluidized bed, spouted bed, plasma, and microwave-assisted reactors for pyrolysis (Park et al., 2019). It is stated that β -scission, end-chain β -scission, and intermolecular and intramolecular hydrogen transfer reactions are essential reaction mechanisms of pyrolysis (Park et al., 2020). A study by Ali et al., 2011 performed polypropylene pyrolysis blended with petroleum residue and coal to obtain a transportation fuel.

Most of propylene are developed by steam cracking of naphtha or low-molecular hydrocarbons (Park et al., 2020).

These extracted recycled polyethylene and polypropylene derivatives were used in road construction as a partial replacement for asphalt/bitumen (Williams-Wynn and Naidoo, 2020). There has been a great deal of research on the replacement of bitumen with plastics, use of plastics in asphalt-concrete mixtures (Appiah et al., 2017; Awoyera and Adesina, 2020; Bahij et al., 2020; Biswas et al., 2020; del Rey Castillo et al., 2020). A study by Hama and Hilal, 2017 concluded that the addition of fine, coarse, and mixed plastic wastes to self-consolidating concrete (SCC) enhanced its fresh properties, such as passing capability and filling capacity, at 12.5% replacement level of plastic by weight of fine aggregate. Furthermore, Khalid et al., 2018 investigated the performance of ring-shaped polyethylene terephthalate (PET) wastes in fibre-reinforced concrete beams. Their study showed that there was no significant impact on the failure mode of plastic fibers applied to concrete, but it improved the mechanical properties of the beams in terms of load at first crack and strength. A study by Arulrajah et al., 2017 also investigated the feasibility of using recycled plastic waste granules (i.e. linear low density polyethylene filled with calcium carbonate (LDCAL), high density polyethylene (HDPE) and low density polyethylene (LDPE)) blends with crushed brick and reclaimed asphalt pavement for road construction. Results showed that the introduction of plastic waste above 5% for road construction material, decreases the blends' stiffness, bearing capacity and robust module. However, the required performance was still achieved, and it has been concluded that the use of plastic waste as aggregate in asphalt improves the pavement's skid and crack resistance (Asi, 2007). A study by Kumi-Larbi et al. (2018) investigated the potential of using low-density polyethylene (LDPE) sheets plastic waste in sand blocks. Their study showed that strong and durable sand blocks can be produced without the need of water. Furthermore, recent study by Aciu et al. (2018) used recycled plastic waste to make sustainable mortars with 75% of plastics as partial sand replacement to obtain M20 grade masonry mortar. The latest invention from mask waste has proved strongly that the face mask can be used for sustainable brick manufacturing (Adlakha, 2020). The sustainable brick was produced with 52% mask waste, 45% paper waste and 3% binder. This brick is alternative to the traditional masonry bricks, which have potential to reduce the plastic waste and cost.

Existing technologies used to extract the plastic derivatives from waste such as mechanical recycling, chemical recycling, incineration and pyrolysis have potential to separate the plastic particle in the mask wastes. The separated plastic derivatives from the mask have the potential to partially replace the cement and aggregates in the construction materials. This is strong, durable, waterproof, light weight, simple to mould and recyclable. Therefore, it can be used in the construction sectors. Further, it can be utilized as air and moisture barriers films and sheets used in insulating the building wraps, industrial adhesive tapes, plastic parts including pipes, masonry bricks. However, there is limited research available as it is a new waste. Therefore, more research needed to ensure the performance, efficiency and economic of construction materials or other products produced from this mask generated plastic wastes.

6. Summary and conclusions

This study analyses the number of different types of face masks usage in Australia, America, UK, Singapore, Sri Lanka, and India, through a public survey analysis. The study reveals that the number of face masks used during the COVID-19 pandemic. Results will help to understand the fundamental inside knowledge of mask waste generation and type of mask. These additional enhanced face masks containing plastic contributed to micro-plastic pollution in the aqua environment and also significantly impact the soil. A detailed study was therefore carried out to identify the difficulties of using more face masks and preventive measures. This paper highlighted the sustainable approach by integrating

the use of natural plant fiber in the woven face mask technology to reduce the plastic waste induced by face masks. Further, upcycling this mask waste and producing construction materials such as artificial aggregates, light weight plastic block and production of ecological mortar can be a viable solution in the near future to reduce the plastic waste and environmental and health impact.

Contributor Roles Taxonomy (CRediT) author statement

K Selvaranjan: Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Review & Editing, Visualization; S Navaratnam: Conceptualization, Methodology, Formal analysis, Writing -Review & Editing, Visualization, Supervision; P Rajeev: Data Curation, Writing - Review & Editing; N Ravintherakumaran: Data Curation, Writing - Review & Editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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